PCT/IL 00/00355
10/019558

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חוק הפטנטים, תשכ״ז - 1967
PATENTS LAW, 5727-1967

בקשה לפטנט
Application For Patent

לשימוש הלשכה
For Office Use

מספר: Number	130711
תאריך: Date	30-06-1999
הוקדם/נדחה: Ante/Post-dated	

אני, (שם המבקש, מענו ולגבי גוף מאוגדת מקום התאגדותו)
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(בעברית) (Hebrew): מערכת תקשורת ושיטה לשימוש בה

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TELECOMMUNICATION SYSTEM AND A METHOD FOR USING SAME

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• בקשת חלוקה Application of Division	• בקשת פטנט מוסף Appl. for Patent of Addition	• דרישת דין קדימה Priority Claim		
מבקשת פטנט from application	• לבקשה/לפטנט to Patent/Appl.	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
No. ___ מס׳	No. ___ מס׳			
Dated ___ מיום	dated ___ מיום			
P.O.A.: • יפוי כח: מצ״ב				
המען למסירת מסמכים בישראל Address for Service in Israel: ד״ר גיל אינגל, אי. סי. איי טלקום בע״מ, ת.ד. 3083, פתח תקווה 49130				

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Signature of Applicant

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For the Applicants,
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היום This 29 בחודש of יוני שנת of the year 1999

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מערכת תקשורת ושיטה לשימוש בה

TELECOMMUNICATION SYSTEM AND A METHOD FOR USING SAME

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ECIP/D006

FIELD OF THE INVENTION

The present invention relates to telecommunication systems in general, and in particular to the transmission of various types of signals in telecommunication systems.

BACKGROUND OF THE INVENTION

Various types of telecommunication systems are known in the patent literature and in the marketplace for interconnecting telephone communication trunks to transmission network. One type of such systems is known as Digital Circuit Multiplication Equipment (to be referred to hereinafter as "DCME") systems.

A particular feature of a typical system is described in Applicant's US 4,523,309. This feature

allows control information such as the assignment, synchronization and identification information to be transmitted along the communication channels instead of on separate signaling channels as in the prior art. In addition, the signaling communication channel assignment information is also supplied via the voice channels rather than via the signaling channels.

There are known DCME systems in which the advantages of Digital Speech Interpolation (DSI) and adaptive pulse code modulation (ADPCM) compression techniques have been incorporated, as demonstrated in applicant's US 4,747,096 which also uses voice channels for the transmission of control information. In addition, the system described in US 4,747,096 detects voiceband data transmission and compresses it according to an optimal ADPCM adapted for voiceband data.

The optimal ADPCM adapted for voiceband data compresses the voiceband data at a typically 2:1 rate whereas the compression rate of the DSI and the ADPCM for speech is 6:1. Thus, with the current proliferation of personal facsimile machines whose signals when transmitted via a DCME are compressed as voiceband data, the overall compression rate of a DCME is approaching 3:1. Still, higher compression rates are achieved when using more advanced encoding algorithms such as LD-CELP and CS-ACELP, with which overall compression rates of 8:1 and 16:1, respectively, can be achieved. Nevertheless, in view of the developing traffic load in telecommunication systems, there is a constant strive for increasing the compression rate which in turn will allow to reduce the communication costs while maintaining the required quality of service.

Applicant's US Re 35,740 describes a method for interconnecting a plurality of communication trunks carrying voice, facsimile and non-facsimile voiceband data signals. The method disclosed by this patent

comprises the detecting of facsimile signals, demodulating the detected signals and transmitting them along the transmission network.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a novel digital telecommunication station capable of transmitting signals of various types.

It is another object of the present invention to provide a digital communication system utilizing efficiently the bandwidth available for communication transmissions.

Yet another object of the present invention is to provide a method for handling various types of communication traffic.

Further objects and features of the invention will become apparent to those skilled in the art, from the following description and the accompanying drawings.

In accordance with the present invention there is provided a digital telecommunication station operative in a first transmission path in a telecommunication network and adapted to receive at least two different types of signals, the station comprising:

at least one detector operative to receive signals and determine their type;

at least one switch controlled by said at least one detector, operative to channel the signals in accordance with the determination of their type;

at least two different pairs of compressing/decompressing devices; and

a first transmission means operative to transmit signals received at the digital communication station along the first transmission path,

wherein signals of at least one type may be diverted from the first transmission path along which signals of the other type(s) are transmitted.

The term "telecommunication network", as will be used hereinafter, should be understood to encompass the various types of networks known in the art, such as TDM, synchronous and asynchronous transfer networks, IP networks, IP frame relaying networks and any other applicable communication networks.

The term "telecommunication station" is used herein to describe a combination of at least two "compressing/decompressing" devices, one of which is used for compressing signals when required, while the other is used as its corresponding de-compressor (e.g. one such device may be an encoder while the other a decoder, etc.). These two devices may be included within one apparatus or be separated from each other.

In accordance with the present invention, the telecommunication station is provided with a detector to determine the type of the signals received and a switch to channel these signals in accordance with their type. However, in some cases, the use of such a detector and a switch can be avoided when a transmissions of certain type(s), are received with *a priori* definition of their type, e.g. assigning pre-defined trunks for specific type(s) of transmission so that when a call arrives via that trunk, the type of the signal is automatically recognized by the station without having to carry any further determination of the signals' type. The present invention should be understood also to encompass this mode of operation.

Preferably, the at least two different types of signals are selected from the group consisting of voice signals, facsimile signals, data signals, voiceband data signals and video signals. More preferably, the signals received by the digital communication station of the

present invention include at least voice and facsimile types of signals.

Optionally, the digital telecommunication station of the present invention further comprises a second transmission means operative to transmit signals diverted from the first transmission path along a second transmission path.

Two main types of signals' diversion are encompassed by the present invention. The one is by delaying the diverted signals (e.g. by storing them in a buffer memory) and forwarding them along that first transmission path towards the receiving end at a later stage. The other type of signals' diversion is carried out by transmitting the diverted signals along a different (second) transmission path, with or without storing them prior to their transmission along that second transmission path.

The major advantages that the present invention offers is in enhancement of the network real time traffic performance as well as its capacity. Diverting part of the traffic carried along the bearer (the first transmission path), results in increasing bandwidth availability for e.g. transmitting additional voice calls, and consequently the overall system performance.

According with a preferred embodiment of the invention, the at least one detector of the digital telecommunication station is operative for detecting facsimile signals on the plurality of communication trunks and classifying the signals received as selected facsimile signals and other signals. The selected facsimile signals may then be diverted (preferably in accordance with the bandwidth availability) from the first transmission path. By another preferred embodiment, the digital telecommunication station further comprises means for encoding/decoding the selected signals, e.g. demodulating/remodulating facsimile signals when

determined to be the selected type of signals, allowing their transmission in their coded form by the digital telecommunication station's second transmission means.

According to yet another preferred embodiment of the invention, the second transmission means transmit the diverted signals along a path defined in a packet network such as an IP network and the like.

It should be understood that the demodulation and remodulation may either be complete including, for example, descrambling and scrambling, or incomplete, not including scrambling and descrambling.

In accordance with yet another preferred embodiment of the invention the demodulating/remodulating means comprises a plurality of facsimile demodulators, apparatus for initially supplying incoming selected facsimile signals simultaneously to the plurality of facsimile demodulators, apparatus for determining which of the plurality of facsimile demodulators initially successfully demodulates an incoming selected facsimile signal, and apparatus for utilizing the facsimile demodulator which initially successfully demodulates an incoming selected facsimile signal for continuing demodulation of the incoming selected facsimile signal. Alternatively, instead of applying a three step procedure, namely, supplying incoming selected facsimile signals to all demodulators, determining which of these demodulators will be used for demodulating the remaining of the transmission and utilizing that demodulator for demodulating the transmission, a two step procedure may be applied. For this alternative, each of the plurality of demodulators is capable of demodulating any type of facsimile transmission received, so that the selection of the demodulator to be used is based primarily on the basis of availability. Once an available demodulator is selected, it is used for demodulating the transmission.

Additionally, in accordance with a preferred

embodiment of the invention the demodulating/remodulating device comprises facsimile signal demodulator/remodulator and forward error correction apparatus wherein the forward error correction apparatus is operative to protect the output of the facsimile demodulator.

In accordance with another embodiment the digital telecommunication station of the present invention further comprises:

first identifier for determining whether the signals received are of a digital compressed form;

second identifier for determining whether the transmission path along which the signals will be transmitted includes at least one further operative means adapted for decompressing the signals when being transmitted in their compressed form;

third transmission means operative in response to a determination made by the second identifier that the transmission path does not include at least one further operative means adapted for decompressing the signals being transmitted in their compressed form; and

forth transmission means operative in response to a determination made by the second identifier that the transmission path does include at least one further operative means adapted for decompressing the signals being transmitted in their compressed form into the decompressed digital output signals.

Such a digital telecommunication station, allows operating mode where signals are received by the station already in their coded form, without having to decompress them when at least one further operative means adapted for decompressing these signals when being transmitted in their compressed form, is operative along the transmission path. Naturally there can be cases where the first transmission path comprises at least one further operative means adapted for decompressing the signals

when being transmitted in their compressed form, whereas the second transmission path does not comprise such further means, or *vice a versa*. In these cases, signals that will be transmitted along the transmission path that does not comprise such further means, will be decompressed to their non-compressed form by the station's decompressing device.

In accordance with yet another aspect of the invention, there is provided a telecommunication system for interconnecting a plurality of telephone communication trunks to a transmission network, the system comprising transmission apparatus at at least a first end of the transmission network and receiving apparatus at at least a second end of the transmission network. The telecommunication system further comprises at least one pair of digital telecommunication station of the type described above.

In accordance with still another preferred embodiment of the invention, a pair of telecommunication stations in the communication system, are selectively operated.

By a further embodiment of the present invention, at least one of the digital telecommunication stations in the digital communication system is further provided with an option of establishing a communication connection with more than two other digital telecommunication stations. Preferably, such a station is adapted to establish a communication with a plurality of digital telecommunication stations, each located at a different part of a telecommunication network. By another embodiment of the present invention, a full or part of a transmission sent by at least one of the telecommunication stations in the digital communication system, may be received in parallel by at least two other digital telecommunication stations.

According to another aspect of the present invention

there is provided a method for interconnecting a plurality of communication trunks carrying at least two different types of signals, to a transmission network, the method comprising:

detecting signals of at least one pre-defined type, as distinguished from signals of other types, and diverting these detected signals from a first transmission path along which signals of the other types are transmitted;

operating on the signals of the other types and transmitting them along a first transmission path; and

transmitting the diverted signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

FIG. 1 is a schematic illustration of an embodiment in accordance with the present invention.

FIG. 2 is a functional block diagram illustration of the transmit side of a system operative in accordance with a preferred embodiment of the present invention;

FIG. 3 illustrates communication links between various telecommunication stations; and

FIG. 4 shows changes in the performance of a telecommunication station of the present invention when operating under various loads of voice, facsimile and voice band data traffic.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

A system illustrating an embodiment of the present invention is shown in Fig. 1. Signals of various types reach telecommunication switch **1** from which they are transmitted over a plurality of trunks **3**, to telecommunication station **5**. According to this

embodiment, a detector (not shown in the Fig.) detects the type of the signals received and a switch (also not shown in this Fig.) controlled by this detector, diverts these signals in accordance with a pre-defined mode of operation. Such pre-defined mode of operation may, for example, be that as long as there is enough available bandwidth for transmission, signals of all types will be transmitted along bearer **7**. However, when traffic load increases, signals of certain type(s), e.g. facsimile signals will be diverted from transmission along bearer **7**. In the latter case, when the signal is of a voice type, it will be processed by station **5** using its internal resources and the bandwidth available in bearer **7** (the first transmission path). When the signal is of a non-fax voiceband data type signal, again, the signal will be processed by station **5** using its internal resources and bearer **7** bandwidth availability. However, when facsimile calls arrive at station **5**, the station's switch diverts them to communication link **11**. The voice and non-fax voiceband signals received at station **9** are decoded and transmitted over trunks **18** towards switch **19**. The diverted facsimile signals are forwarded via communication link **11** and via IP gateway **13**, towards IP network **15**. The diverted facsimile signals are then transmitted over an IP path defined in network **15** towards gateway **17**. In gateway **17**, the arriving facsimile calls are directed to station **9** where they are channeled in accordance with the original assignment of trunks **18** to switch **19**, and therefrom, to their respective destinations. It should also be understood that in accordance with a preferred embodiment of the present invention, the diverted facsimile signals should not necessarily be transmitted via station **9**. A different path can be applied, as long as the diverted signals can be managed and controlled by the network so that they

reach successfully their destination.

Reference is now made to FIG. 2, which is a functional block diagram of a telecommunication station. The transmit side is described with respect to FIG. 2. The receive side is mirror symmetric and will not be described with respect to FIG. 2. Many of the components of the telecommunication system are substantially similar to those described and claimed in the aforesaid U.S. Pat. No. 4,717,096, which is incorporated herein by reference, and therefore, will not be described in detail. It will be appreciated that the telecommunication system described in FIG. 2 can be implemented in a point to point configuration, in a multiclique configuration, and in a multi-destination configuration, as defined in ITU-T Recommendation G.763. Additionally, it can be implemented as an access terminal for traffic compression into a packet switching network.

The transmission apparatus includes a trunk PCM interface (TDLI) **20** which is operative to provide interfacing between 1.544 Mbit/s or 2.048 Mbit/s PCM signals and the internal 2.048 Mbit/s (NRZ) signals employed in the telecommunication system. It is operative to provide synchronization plesiochronous buffering and optional format conversion.

Downstream of TDLI **20** there is provided a time slot interchange (TSI) **22** which provides time slot mapping. It enables up to ten 24-channel bit streams to be regrouped into eight 30/32 channel bit streams.

Digital speech interpolation circuitry (DSI) **24** provides voice compression by means of the time assignment speech interpolation (TASI) e.g. of US 4,523,309.

Detector **21** provides detection circuitry for classifying incoming signals as selected signals of a pre-defined type(s), such as facsimile signals, and as other signals where other signals typically include

speech, tone and non-facsimile voiceband data. In accordance with this detecting operation, switch **23** channels the signals in accordance with their type. This enables the transmission apparatus to separately compress facsimile signals and transmit them along a second transmission path and to apply the conventional compression techniques for speech and non-facsimile voiceband data signals, and transmit them along a first transmission path.

Further compression is provided by a signal compression circuit typically comprised of a speech compressing circuitry **26**, which can be Adaptive Differential Pulse Code Modulation (ADPCM) circuitry, LD-CELP circuitry, CS-ACELP circuitry and the like, and Variable Bit Rate (VBR) circuitry **28**, voiceband data optimized algorithm circuitry **27** and optionally facsimile modem **29**. Facsimile modem **29** is optionally included mainly to retain the option of transmitting the facsimile signals along with the other types of signals when there is enough bandwidth available.

Speech compressing circuitry **26** may employ an ADPCM algorithm, in accordance with ITU-T Recommendation G.726, LD-CELP algorithm in accordance with ITU-T Recommendation G.728, CS-ACELP algorithm in accordance with ITU-T Recommendation G.729 and similar ones for compressing speech. VBR circuitry **28** is typically provided in conjunction with ADPCM **26** and is operative to effectively create additional bearer channels (in excess of 62) to overcome periods of traffic overload, as described in aforesaid U.S. Pat. No. 4,747,096. The ADPCM **26** and the VBR **28**, in conjunction with the DSI 24, provide a compression ratio of typically 6:1 for speech signals.

Voiceband data is routed through voiceband data optimized algorithm **27** which employs ADPCM codecs specifically optimized for reliable transmission of

voiceband data, as described in aforesaid U.S. Pat. No. 4,747,096. It will be appreciated that the voiceband data compression may be implemented using other algorithms, such as that of ITU-T Recommendation G.726.

In accordance with a preferred embodiment of the present invention, facsimile signals are channeled by switch **23** to facsimile modem **33** provided for reproducing a plurality of original facsimile binary data from a plurality of PCM signals, for optionally incorporating error correction information into the plurality of original facsimile binary data and for multiplexing the resultant signals. The optional error correction function is typically provided when the transmission network is of the type where performance is typically degraded. From previous explanations it should be clear that the device designated as facsimile modem **33** is not necessarily used to demodulate facsimile signals, and to be used as a means to transfer the diverted facsimile signals to the second transmission path without operating thereon. Multiplexer **34** multiplexes the output of facsimile modem **33** into a plurality of time slots of up to 2.048 or 1.544 Mbit/s signal.

Multiplexer **31** multiplexes the output of the signal compression stage, comprising speech compressing algorithm **26**, VBR **28**, voiceband data algorithm **27** and facsimile modem **29** (if applicable) into a plurality of time slots of up to 2.048 or 1.544 Mbit/s signal.

An alternative embodiment of the invention comprises a multiplexer **31** which incorporates wideband packet technology, as described in the aforementioned paper by R. W. Muise *et al* entitled "Experiments in Wideband Packet Technology" presented at the International Zurich Seminar on Digital Communication, April 1986. In the alternative embodiment, the multiplexer **31** is operative to act as a Packet Assembler (PA) to gather and packetize

a sequence of samples of compressed speech, voiceband data or facsimile data (when applicable) and to subsequently transmit the packets to a transmission network.

Interface between the 2.048 Mbit/s output from the multiplexer **31** to the standard 1.544/2.048 Mbit/s standard PCM bearer channels is provided by the Bearer PCM Interface (BDLI) **30**, described in aforesaid U.S. Pat. No. 4,747,096. Similarly, a further BLDI **35** is provided to allow facsimile transmission via a different transmission path.

It will be appreciated that a facsimile compression system such as described hereinabove can be constructed outside of an telecommunication system using elements functionally similar to those described hereinabove. However, incorporating such a system within an existing system, such as a digital circuit multiplication system or a speech packetization system, reduces the number of new elements which must be built since many of the necessary elements are already incorporated into the existing system.

Another embodiment of the invention is illustrated in this Fig. 3. In accordance with this embodiment a telecommunication system (in this example station **110**) may communicate with more than one corresponding counterpart thereof. In this Fig., station **110** is illustrated as having an option to communicate with both stations **120** and **130**. As should be appreciated by a man skilled in the art, this embodiment may be implemented in a variety of ways. One example of such implementation, is that each of the stations may communicate with any other corresponding station, each located at a different end of an IP net, where voice calls may be directed to station **120** and fax calls to station **130**. Another applicable example is that a station may communicate simultaneously with at least two corresponding stations, each receiving

for example one or more pre-defined types of signals. Further types of operating digital telecommunication stations in tandem are also possible, and it should be understood that they are all encompassed by the present invention.

Let us now turn to Fig. 3 in which two pairs of telecommunication stations, namely, **100** and **200** are shown. Each one of these two pairs of stations comprises one station operating as a compressor (**110** and **210**, respectively) and its counter de-compressor (**120** and **220** respectively). A typical operation of these stations is as follows. A transmission is received at station **110** operating as a compressor. The facsimile signals are diverted to station **130** and the rest of the transmission is compressed and sent to station **120** operating as a de-compressor. Once identification means of station **120** determine the existence of another operative pair of telecommunication stations (**200**), e.g. by detecting identification signal(s) transmitted by station **210**, the end-to-end compression mode of operation is established, and the transmission will be transmitted from station **120** to station **210** in its compressed form. The transmission thus received at station **210** is further transmitted to the de-compressor **220**, for decompression. The facsimile signals may for example be transmitted in their demodulated form to station **210** as long as the parameters of the calls can be retrieved, e.g. keeping track after these parameters by using an outband system such as one operating in a compatible SS7 network.

When the transmission direction is reversed, the transmission arriving is compressed by station **220**, now operating as a compressor, and sent to station **210**. The latter station, identifying the existence of a further operative pair of stations (**100**), now downstream of the transmission path, will transmit the information received

in its compressed mode. The compressed information will then be transmitted by device **110** operating now as the compressing device in the pair (**100**) of stations, to the now de-compressing device **110**, where it will be decompressed.

In recent years, enhanced voice compression capabilities are being used, such as by using the LD-CELP and CS-ACELP compressing algorithms. However facsimile traffic, which demonstrates an increase in transmission over DCME systems, mainly during business traffic period and during lower tariff time of the day, has a negative affect upon the DCME systems. When such a system can achieve 10:1 gain when voice calls are transmitted, this gain is decreased to about 6:1 for facsimile calls. Fig. 4 illustrates typical system gain as a function of various combinations of voice, fax and voiceband data ("VBD") traffic.

The set of conditions chosen as a basis for the performance presented in this Fig. are: bearer bandwidth - 2 Mbit/s; Fax - 90% of VBD; Fax TX% - 75% of fax transmissions; Non-fax VBD - 40 kbit/s FDX; Average Bit Per Sample (ABPS) - 1.88 for LD-CELP and 3.7 for ADPCM; and freeze out - <0.1%. Curve **a** presents a system using the LD-CELP speech compressing algorithm (based on ITU-T Recommendation G.728) whereas curve **b** presents a system using ADPCM algorithm (based on ITU-T Recommendations G.763 and G.766). As can be seen in this Fig., in case of 40% VBD calls, out of which about 90% are actually facsimile calls, the system achieves gain of 263 trunk channels compressed to 31 time slots, demonstrating an average gain of 8.48:1, where 95 trunks are used for carrying facsimile calls. When these facsimile calls are diverted as suggested by the present invention to IP bearer, the average gain is increased to 9.8:1 whereas 3 additional trunks will used to carry facsimile traffic.

This type of operation allows the major part of the TDM network bandwidth to be assigned for voice transmission which is sensitive to delay, variations in delay periods as well as loss of data, while other traffic such as facsimile transmissions, less sensitive to delays, is transferred to the IP network.

It is to be understood that the above description only includes some embodiments of the invention and serves for its illustration. Numerous other ways of managing various types of compressed signals in telecommunication networks may be devised by a person skilled in the art without departing from the scope of the invention, and are thus encompassed by the present invention.

Claims:

1. A digital telecommunication station operative in a first transmission path in a telecommunication network and adapted to receive at least two different types of signals, the station comprising:

at least one detector operative to receive signals and determine their type;

at least one switch controlled by said at least one detector, operative to channel the signals in accordance with the determination of their type;

at least two different pairs of compressing/decompressing devices; and

a first transmission means operative to transmit signals received at the digital communication station along the first transmission path,

wherein signals of at least one type may be diverted from the first transmission path along which signals of the other type(s) are transmitted.

2. A digital telecommunication station according to Claim 1, further comprising a storage capable of storing diverted signals of said at least one type.

3. A digital telecommunication station according to Claim 1 or 2, further comprising a second transmission means capable of transmitting diverted signals of said at least one type via a second transmission path.

4. A digital telecommunication station according to any one of the preceding Claims, wherein the signals of said at least one type to be diverted are facsimile signals.

5. A digital telecommunication station according to Claim 4, further comprising a device for demodulating/remodulating said facsimile signals.

6. A digital telecommunication station according to Claim 5, wherein said demodulating/remodulating device comprises facsimile signal demodulator/remodulator and forward error correction apparatus wherein the forward error correction apparatus is operative to protect the output of the facsimile demodulator.

7. A digital telecommunication station according to any one of the preceding Claims further comprising:

first identifier for determining whether the signals received are of a digital compressed form;

second identifier for determining whether the transmission path along which the signals will be transmitted includes at least one further operative means adapted for decompressing the signals when being transmitted in their compressed form;

third transmission means operative in response to a determination made by the second identifier that the transmission path does not include at least one further operative means adapted for decompressing the signals being transmitted in their compressed form; and

forth transmission means operative in response to a determination made by the second identifier that the transmission path does include at least one further operative means adapted for decompressing the signals being transmitted in their compressed form into the decompressed digital output signals.

8. A telecommunication system for interconnecting a plurality of communication trunks to a transmission network, the system comprising transmission apparatus at at least a first end of the transmission network and receiving apparatus at at least a second end of the transmission network and at least one pair of digital telecommunication station of any one of the preceding Claims.

9. A telecommunication system according to Claim 8, wherein at least one pair of said telecommunication stations, are selectively operated.

10. A telecommunication system according to Claim 8, wherein at least one of the digital telecommunication stations is provided with an option of establishing a communication connection with more than two digital telecommunication stations.

11. A method for interconnecting a plurality of communication trunks carrying at least two different types of signals, to a transmission network, the method comprising:
different types of signals, to a transmission network, the method comprising:

detecting signals of at least one pre-defined type, as distinguished from signals of other types, and diverting these detected signals from a first transmission path along which signals of the other types are transmitted;

operating on the signals of the other types and transmitting them along a first transmission path; and

transmitting the diverted signals.

For the Applicants,
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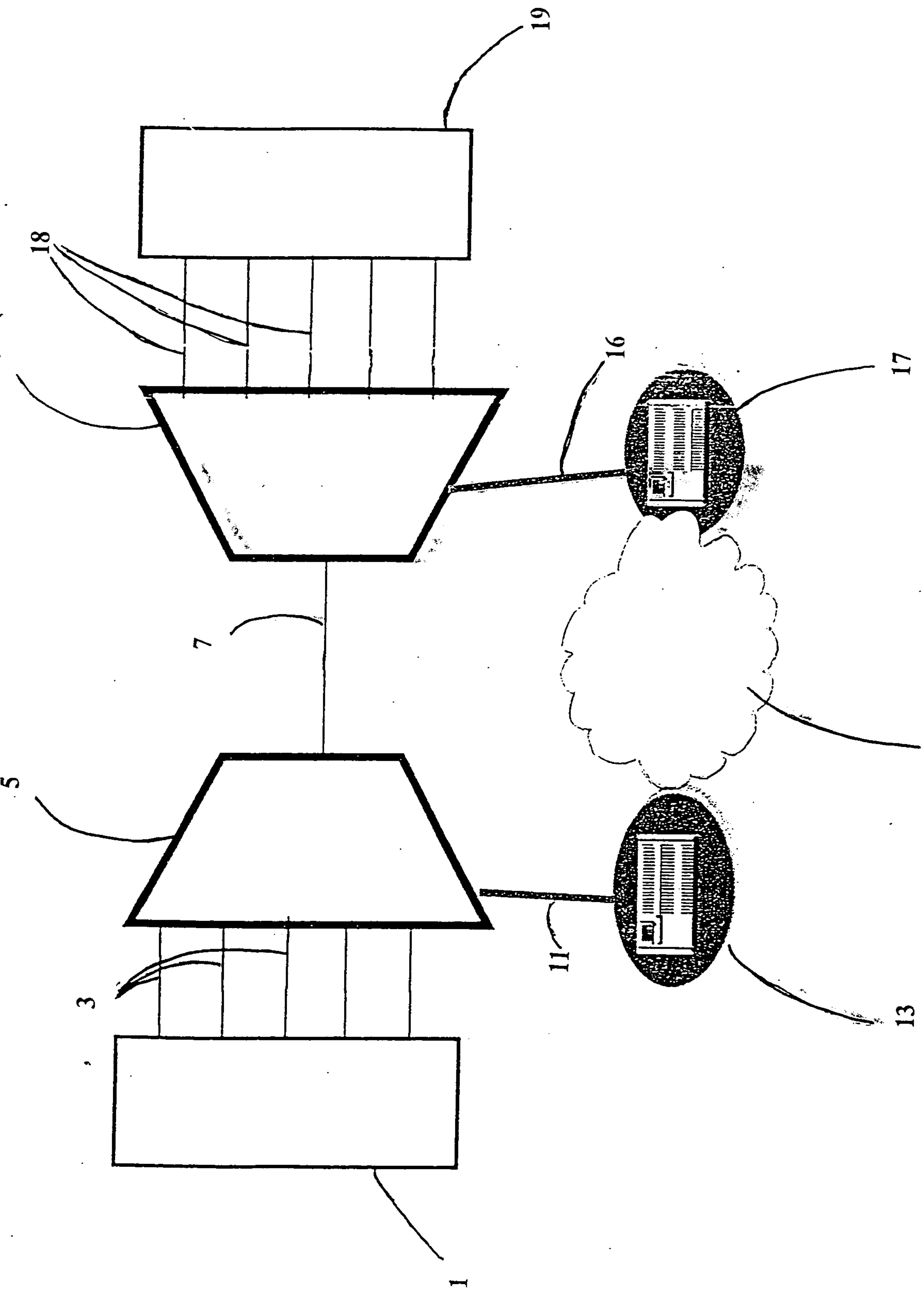

Fig. 1

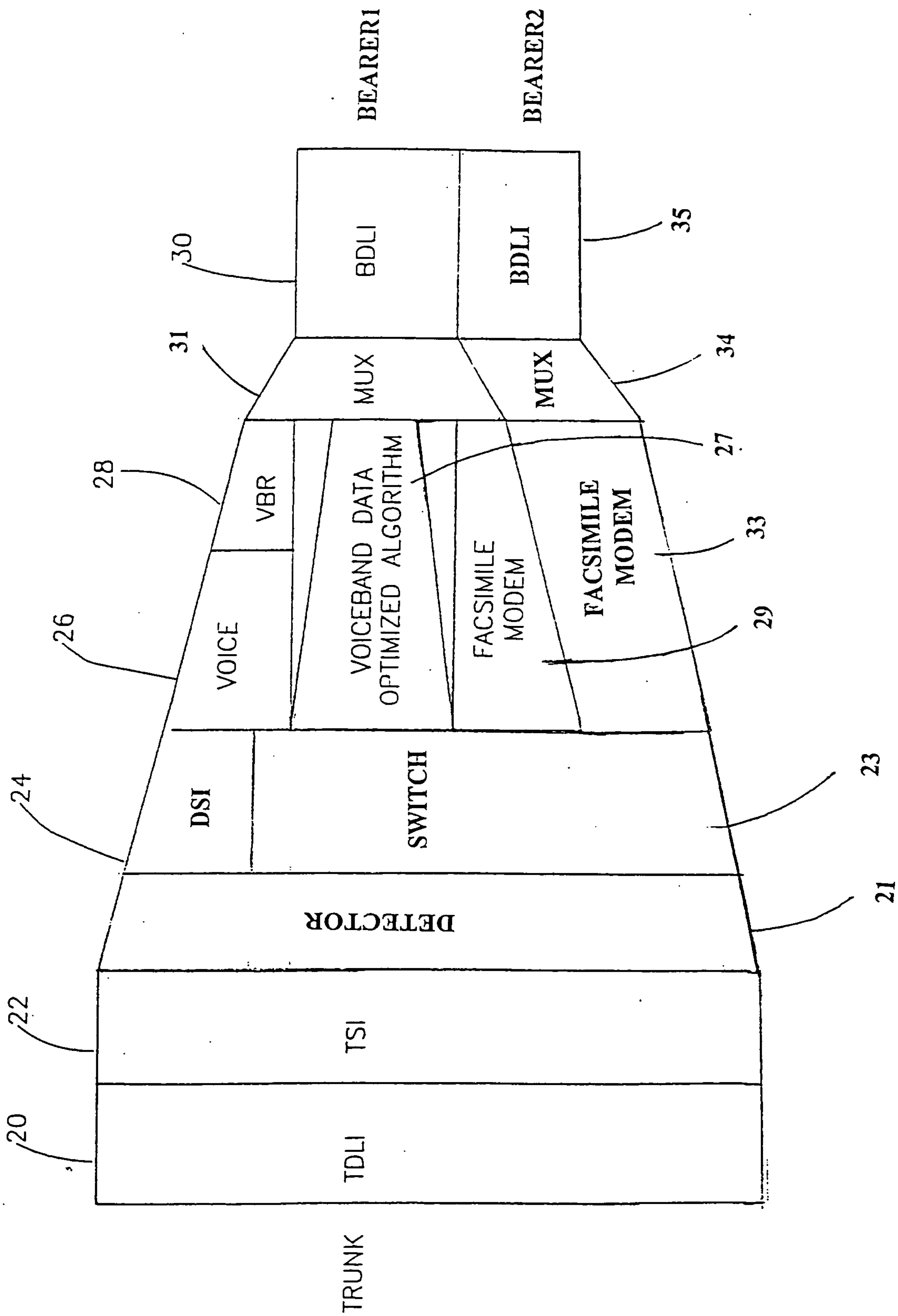
BEARER1
BEARER2
BDLI
BDLI
30
35
MUX
MUX
31
34
VBR
28
VOICEBAND DATA OPTIMIZED ALGORITHM
27
FACSIMILE MODEM
FACSIMILE MODEM
33
29
VOICE
26
DSI
SWITCH
24
23
DETECTOR
21
TSI
22
TDLI
20
TRUNK

Fig. 2

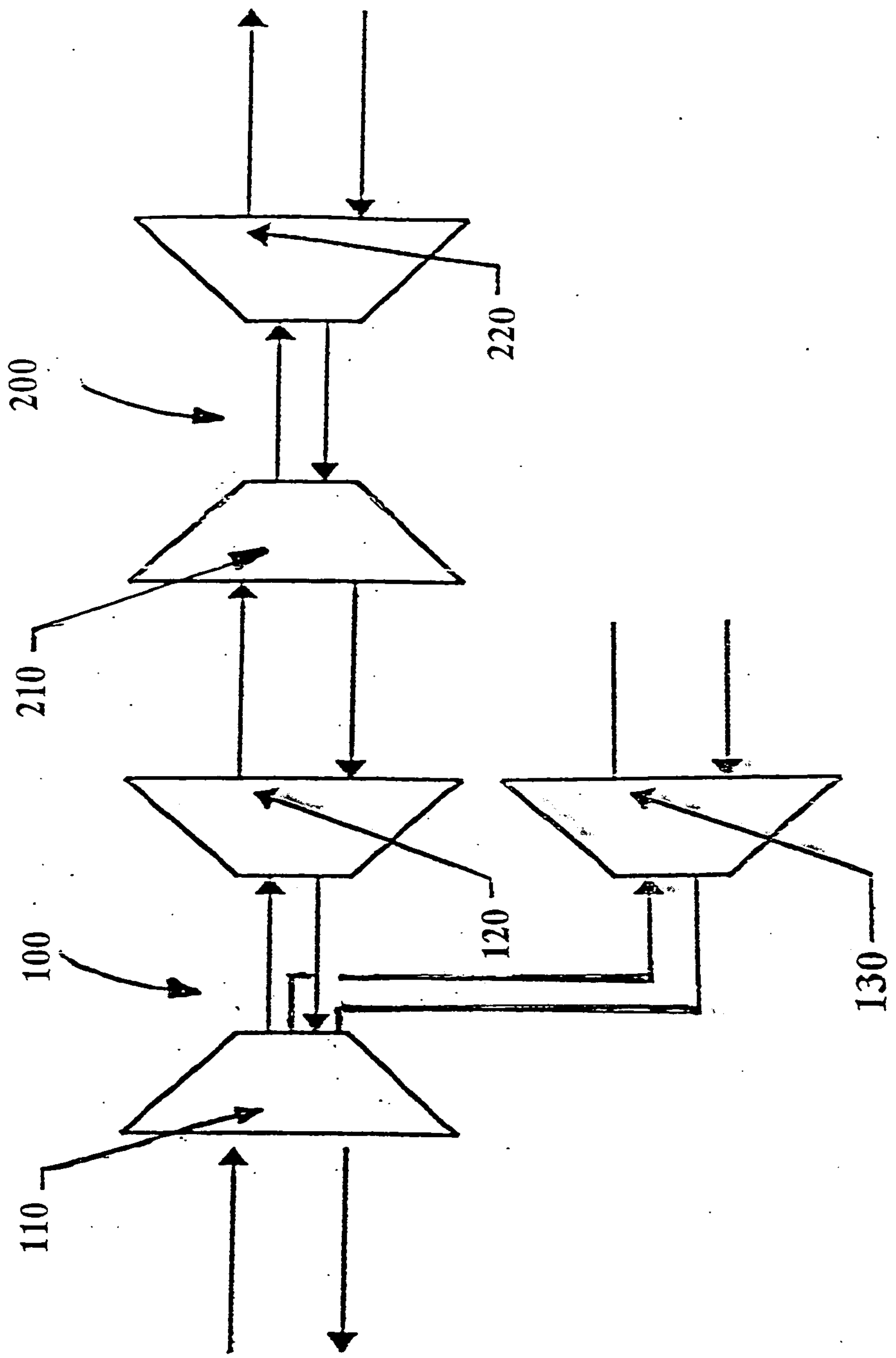

Fig. 3

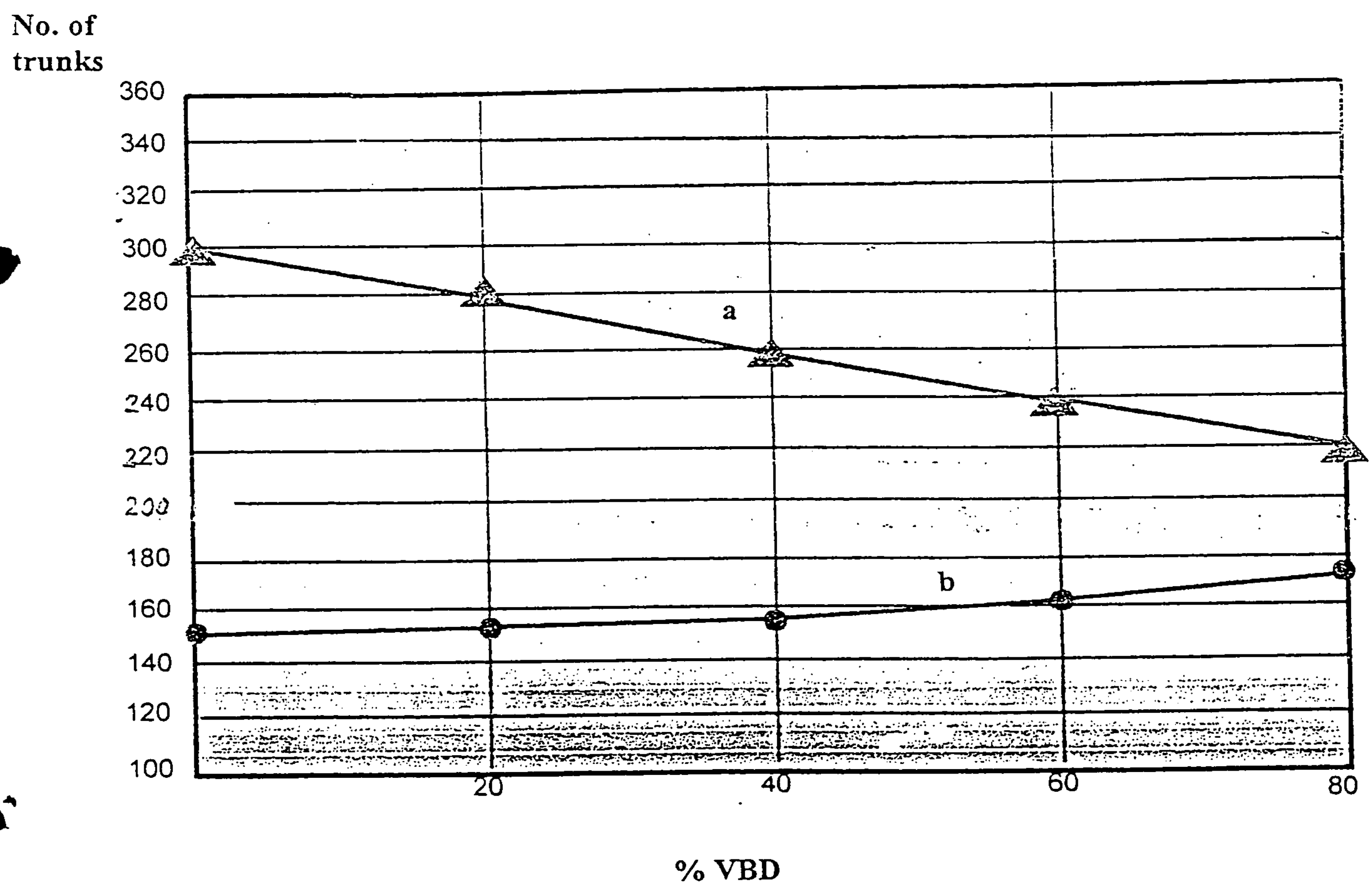
No. of trunks
360
340
320
300
280
260
240
220
200
180
160
140
120
100
20
40
60
80
a
b
% VBD

Fig. 4